

PATENT SPECIFICATION

(11) 1376910

1376910

- (21) Application No. 60661/71 (22) Filed 30 Dec. 1971
 (31) Convention Application No. 103252 (32) Filed 31 Dec. 1970 in
 (33) United States of America (US)
 (44) Complete Specification published 11 Dec. 1974
 (51) International Classification H01S 3/18
 (52) Index at acceptance

H1C 213 214 22Y 230 231 232 233 23Y 24Y 25Y 353
 355 35Y 361 366 36Y 392 39Y 401 475 476 508
 521 523 52Y 530 532 537 63Y 710 720 723 724
 73Y
 C4S 68X 68Y 713 71Y 730 731 733
 H1K 211 222 271 273 287 323 341 34Y 40X 422 455
 459 489 579 581 583 586 591 598 59Y 60Y 61Y
 625 62Y



(72) Inventor IZUO HAYASHI

(54) SEMICONDUCTOR BODIES FOR SEMICONDUCTOR INJECTION LASERS

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED of 195 Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to semiconductor bodies used in semiconductor injection lasers.

In our copending application No. 11536/71 (Serial No. 1342767), there is described, among other things, a double heterostructure (DH) semiconductor laser diode comprising a narrow bandgap active region sandwiched between a pair of opposite conductivity type wider bandgap regions thereby forming a pair of heteroboundaries, one at each interface with the narrow bandgap region. A p-n junction is located at or between the heteroboundaries. The difference in bandgap at each interface has two effects: it produces an electric field at each interface which serves to confine injected carriers to the active region, and it produces a discontinuity in index of refraction at each interface which serves to confine photons to the active region. In the active region, therefore, both carrier concentration (and hence gain) as well as the coupling between the confined carriers and photons are enhanced resulting in lower thresholds and a lower temperature dependence of the threshold. As reported by M. B. Panish, P. W. Foy, S. Sumski and I. Halashi in *Applied Physics Letters*, 17, 109 (August 1970, this type of DH laser diode has been successfully operated on a c.w. basis at room temperature. The diode was fabricated from

GaAs—AlGaAs

by a liquid phase epitaxial technique described in copending application No. 26731/71 (Serial No. 1332942).

As discussed in our aforementioned copending application 11536/71 (Serial No. 1342767) the upper limit on thickness of the narrow bandgap active region is preferably less than one micron in order that high carrier concentrations and hence low thresholds be obtained. From the standpoint of obtaining high carrier concentrations, therefore, it would be desirable to use active regions as thin as possible, thereby producing high gain and low thresholds. In practice however, other considerations dictate that a lower limit on the thickness of the active region occurs at approximately one half the wavelength ($\lambda/2$) of the stimulated recombination radiation as measured in the semiconductor (about 0.125 μm for GaAs). Below approximately $\lambda/2$ several competing mechanisms take place: the tails of the optical field, which extend outside the active region into a lossy region, increase in size resulting in increased optical loss (absorption), reduced coupling between confined carriers and photons, and hence lower gain; simultaneously, the thinness of active region increases carrier concentration and hence increases gain. Analysis indicates, however, that the net effect of these competing mechanisms is higher thresholds or at best no net advantage of active regions less than about $\lambda/2$ in thickness.

According to the invention, a semiconductor body comprises first and second wide bandgap semiconductor regions of opposite conductivity type, a first narrow bandgap active region between and contiguous with said first and second regions, a second narrow bandgap

active region within said first active region, the bandgap of said second active region being smaller than the bandgap of said first active region, a p-n junction located within or coincident with one of the boundaries of said second active region, the arrangement being such that when a suitable operating potential is applied to the body carriers injected under forward bias across said junction are confined to said second active region where they undergo radiative recombination to generate stimulated coherent radiation, said radiation being confined substantially to said first active region, the thickness of said first active region being between approximately $\lambda/2$ and λ , where λ is the wavelength of said radiation as measured in said semiconductor body.

A laser embodying the invention includes a first narrow bandgap active region and a second narrow bandgap active region within the first region, with the bandgap of the second region being narrower than that of the first region. The first active region is between about $\lambda/2$ and λ in thickness and serves to provide optical confinement, whereas the second active region, which may approach a few hundred angstroms in thickness, serves to provide carrier confinement. It should be noted that the designation of the first region as an "active" region deviates somewhat from the conventional usage in the prior art which considers the active region as that region in which recombination of holes and electrons takes place. In the improved DH laser, recombination takes place in the second active region which, however, is included within, but is thinner than, the first active region.

Analysis of this structure indicates that as the thickness (d_2) of the second region decreases, the following changes take place: the optical losses remain approximately constant since the thickness (d_1) of the first region is fixed; carrier concentration (n) increases approximately linearly; optical coupling (Γ) decreases approximately linearly; and gain, which is approximately proportional to $n^2\Gamma$, increases approximately linearly with decreasing d_2 . Consequently, it is expected that the improved DH laser will exhibit higher gain and lower thresholds than the earlier form of DH laser.

The invention can be more easily understood from the following detailed description of an embodiment taken in conjunction with the drawing, in which:

Fig. 1 shows the layered structure of a typical prior art form of DH laser in part A and shows the illustrative bandgap profile, refractive index profile, and light intensity distribution of such a laser in parts B, C and D respectively;

Fig. 2 is a graph of current threshold density as a function of active region thickness for the prior art form of DH laser;

Fig. 3A shows a typical index of refraction profile and light intensity distribution in the prior art form of DH laser; Fig. 3B is a graph of the fraction of light confined to the active region as a function of the thickness of the active region for such a DH laser;

Fig. 4 in part A shows the layered structure of an improved DH laser in accordance with an illustrative embodiment of the invention and in parts B, C, and D show the bandgap profile, refractive index profile and light intensity distribution of such a laser, respectively; and

Fig. 5 is a schematic of the DH laser of Fig. 4, part A mounted on a heat sink.

Before discussing the invention in detail, a brief analysis of an earlier form of DH laser will be presented for the purposes of comparison. As shown schematically in Fig. 1, part A, such a DH laser typically comprises an n-type gallium arsenide substrate 12 on which are grown by a liquid phase epitaxial technique three layers in the sequential order following: an n-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 14, a GaAs or $\text{Al}_y\text{Ga}_{1-y}\text{As}$ layer 16 with $y < x$ and a p-type $\text{Al}_z\text{Ga}_{1-z}\text{As}$ layer 18 with $y < z$. For simplicity the electrical contacts to the substrate 12 and layer 18 of the laser diode have been omitted. By controlling the aluminium concentration in layers 14, 16 and 18, the active layer 16 is made to have a narrower bandgap than either of layers 14 or 18, thereby forming a pair of heteroboundaries 20 and 22 at the interfaces between layers 14 and 16 and between layers 16 and 18 respectively. A p-n junction 11 is located between the heteroboundaries 20 and 22 or may be coincident with one of them.

Associated with each heteroboundary is a discontinuity (or step) in the bandgap energy profile as shown at 20b and 22b in Fig. 1, part B. The effect of this discontinuity is to create an electric field which reflects injected electrons at heteroboundary 22 and reflects injected holes at heteroboundary 20, thereby effectively confining injected carriers to the active layer 16. These carriers produce a population inversion between the conduction and valence bands resulting in radiative recombination of holes and electrons and the emission of stimulated coherent radiation characteristic of the bandgap in the active layer 16.

Also associated with each heteroboundary is a discontinuity in index of refraction as shown at 20c and 22c in Fig. 1, part C, which forms an optical waveguide to confine the photons generated in the recombination process to the active region as shown by the light intensity distribution of Fig. 1, part D.

As shown in Fig. 2, the current density threshold J_{th} of the earlier form form of DH laser decreases approximately linearly as a function of d , the thickness of the active

layer 16 for $\lambda/2 < d < 3 \mu\text{m}$, where λ is the wavelength of the stimulated radiation as measured in the active layer. As the thickness of the active layer, however, is decreased below $\lambda/2$, the threshold begins to increase (Fig. 2, curve I) or at best remains constant (Fig. 2, curve II) depending on how the active layer is doped and other parameters. A qualitative understanding of this phenomenon can be had from the following brief explanation. In the earlier form of DH laser, to a first approximation, the gain is proportional to the product $n^2\Gamma$ for a structure in which $d < \lambda/2$, where n is the carrier concentration

in the active layer and Γ is the coupling between confined carriers and the optical field in the active layer. Since the coupling is approximately directly proportional to d^2 and since the carrier concentration is proportional to d^{-1} , the net effect of decreasing d is to produce no net increase in gain. It should be noted that the exponents here were chosen for the purposes of simplicity and are not intended to reflect the actual exponents which can be empirically determined. Thus, in this form of DH laser it is difficult to take advantage of the increase in carrier concentration which results from thin active layers because reducing d sacrifices optical coupling.

A quantitative measure of the loss in coupling is depicted in Fig. 3A where the light intensity distribution is plotted along with the index of refraction profile for this DH laser structure. The optical coupling Γ is defined as the fraction of light confined to the active layer as compared with the total amount of light generated. It can be seen from the graph of Fig. 3B (Γ as a function of d) that as the thickness of the active layer is reduced, Γ decreases rapidly until Γ is only about 20% for $d \approx \lambda/2$. Consequently, 80% of the stimulated radiation is distributed in the tails of the optical field which extend outside the active layer. These tails do not undergo radiative recombination (i.e., are not coupled to the confined carriers) and furthermore increase optical absorption, since they extend into adjacent lossy layers.

In accordance with an illustrative embodiment of the invention, for DH structures in which the active layer is between approximately $\lambda/2$ and λ in thickness there is included a second active layer within the usual active layer (hereinafter termed the first active layer) having a bandgap narrower than that of the first layer. The structure of our modified DH laser is shown in detail in Fig. 4, part A in which identical numerals have been utilized for components corresponding to the earlier form of DH laser of Fig. 1, part A. The improved DH laser illustratively comprises an n-type GaAs substrate 12 upon which are epitaxially grown the following layers in

the sequential order recited, an n-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 14; an n-type $\text{Al}_y\text{Ga}_{1-y}\text{As}$ layer 15 with $y < x$; a GaAs or $\text{Al}_p\text{Ga}_{1-p}\text{As}$ layer 17 with $p < y$; a p-type $\text{Al}_q\text{Ga}_{1-q}\text{As}$ layer 19 with $p < q$, and a p-type $\text{Al}_z\text{Ga}_{1-z}\text{As}$ layer 18 with $q < z$. A first pair of heteroboundaries 20 and 22 are formed at the interfaces between layers 14 and 15 and layers 18 and 19, respectively, and a second pair of heteroboundaries 21 and 23 are formed at the interface between layers 15 and 17 and between layers 17 and 19 respectively. A p-n junction 11 is located between heteroboundaries 21 and 23 or is coincident with one of them. For simplicity the contacts have been omitted.

Associated with each heteroboundary 21 and 23 is an energy step in the bandgap profile as shown at 21b and 23b in Fig. 4, part B. This step creates an electric field which serves to reflect electrons at heteroboundary 23 and to reflect holes at heteroboundary 21, thereby confining the injected carriers to the second active layer 17. Associated with each heteroboundary 20 and 22, on the other hand, is a discontinuity in the refractive index as shown at 20c and 22c in Fig. 4, part C, which forms an optical waveguide to confine the optical radiation to the first active layer between heteroboundaries 20 and 22.

A qualitative analysis of the improved DH laser is as follows. Assuming that the thickness d_1 of the first active layer (the function of which is to produce optical confinement) is fixed, the optical losses remain approximately constant, but, as with the earlier form of DH laser, carrier concentration increases and optical coupling decreases as the thickness d_2 of the second active layer 17 is decreased. Although in both types of DH laser (1) gain is approximately proportional to $n^2\Gamma$ and (2) n is proportional to d_2^{-1} , in the improved DH laser Γ is proportional to d_2 and not d_2^2 as in the earlier form of DH laser. The net effect is that optical losses remain constant while gain increases approximately linearly with decreasing d_2 , thereby resulting in lower thresholds than otherwise attainable. Once again, the exponents have been chosen as integers for simplicity only.

It should be noted that optical losses can be further reduced if the second active layer 17, instead of being centrally located within the first active layer, is disposed nearer to heteroboundary 22. In such a structure advantage is taken of the fact that less optical absorption occurs in the n-type layer 15 than in the p-type layer 19.

In a preferred embodiment, the active regions are made symmetrical, i.e., energy steps 20b and 22b are equal (forming a symmetrical waveguide) as are energy steps 21b and 23b, or equivalently $y \approx q < x \approx z$. Furthermore, steps 20b and 22b are prefer-

ably greater than steps 21b and 23b, or equivalently

$$(y-p) < (x-y) \text{ and } (q-p) < (z-q),$$

since fewer eV are required to confine electrons than photons.

By way of illustration, the index of refraction steps 20c and 22c at heteroboundaries 20 and 22 respectively are typically in the range of 5% to 10% (as compared to the index of refraction of pure GaAs) whereas the index of refraction steps 21c and 23c at heteroboundaries 21 and 23 respectively are about 1% to 2%. The corresponding bandgap steps 20b and 22b at heteroboundaries 20 and 22 respectively are about 300 to 500 meV, whereas the energy steps 21b and 23b at heteroboundaries 21 and 23 respectively are typically about 50 to 100 meV.

Turning now to Fig. 5, there is shown an illustrative embodiment of my invention in which the multi-layered improved DH laser of Fig. 4, part A is mounted upon a heat sink for c.w. operation at room temperature. In the following description materials and dimensions are given for the purposes of illustration only. As discussed previously, the improved DH laser comprises an n-type GaAs substrate 12 about 3—4 mils thick upon which are sequentially fabricated epitaxial layers: an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 14 about 3 μm thick, a first active layer between heteroboundaries 20 and 22 which is about 0.2 μm thick, a second active layer 17 within the first active layer which is typically about 0.1 to 0.03 μm thick, and a p-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 18 which is 1 μm in thickness. Typically region 15 is n-type whereas region 19 is p-type, but the second active layer 17 may be either p-type or n-type.

Before depositing a metallic contact 25 onto the n-type substrate 12, a p-type dopant (e.g., zinc) is typically diffused into p-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 18 to form a shallow (e.g., 0.2 μm) p^+ layer (not shown) to provide good ohmic contact. On p-type layer 18 is deposited an oxide layer 27 having an elongated channel etched therein by well-known photolithographic techniques to define a stripe electrical contact formed by the deposition of a metal layer 29 thereover.

End faces 31 and 33 of the structure are typically cleaved or polished optically flat and perpendicular to the p-n junction (not shown) to form an optical cavity resonator for sustaining coherent radiation generated in the junction. Illustratively, the diode is about 400 μm long and 80 μm wide. One of the end faces is made nearly totally reflective (e.g., face 33) whereas the other (face 31) is made partially transmissive in order to provide a means of egress for the coherent radiation.

In operation the laser diode by means well known in the art is forward-biased and

pumped by a dc source in excess of the lasing threshold. For c.w. operation at room temperature and above, contact 29 may be bonded to a metallized (e.g., tin plated) high thermal conductivity diamond 35 mounted on a tin-plated copper heat sink 37. Due to the difficulty in getting the tin-plating to cover the entire diamond 35, gold wires 39 (about 25 μm in diameter) may be used to ground the tin-plated top surface 41 of the diamond to the heat sink 37. For low thresholds (e.g., 3000 A/cm²) the diamond may be omitted and the diode mounted directly on the copper heat sink. Furthermore, improved heat extraction may be obtained by mounting the diode between a pair of heat sinks.

In the fabrication of our improved DH laser it should be remembered that extremely thin layers are utilized, e.g., the thickness of the first active layer, which serves to provide optical confinement, may be about 0.1 to 0.2 μm whereas the thickness of the second active layer, which serves to confine carriers, may approach an electron diameter (about 100 Å). It is therefore preferable to employ a molecular beam epitaxial growth technique which readily permits the growth of epitaxial layers of III—V compounds as thin as 100 to 200 Å, and is described in our application No. 62287/69 (Serial No. 1270550). That application further describes techniques for growing mixed crystals of III—V compounds such as AlGaAs as well as techniques for introducing into the epitaxial layers either p-type or n-type dopants.

WHAT WE CLAIM IS:—

1. A semiconductor body comprising first and second wide bandgap semiconductor regions of opposite conductivity types, a first narrow bandgap active region between and contiguous with said first and second regions, a second narrow bandgap active region within said first active region, the bandgap of said second active region being smaller than the bandgap of said first active region, a p-n junction located within or coincident with one of the boundaries of said second active region, the arrangement being such that when a suitable operating potential is applied to the body carriers injected under forward bias across said junction are confined to said second active region where they undergo radiative recombination to generate stimulated coherent radiation, said radiation being confined substantially to said first active region, the thickness of said first active region being between approximately $\lambda/2$ and λ , where λ is the wavelength of said radiation as measured in said semiconductor body.

2. A body according to claim 1 wherein said second active region is disposed nearer to the one of said wider bandgap regions which is p-type rather than the wider bandgap region which is n-type.

ably greater than steps 21b and 23b, or equivalently

$$(y-p) < (x-y) \text{ and } (q-p) < (z-q),$$

5 since fewer eV are required to confine electrons than photons.

By way of illustration, the index of refraction steps 20c and 22c at heteroboundaries 20 and 22 respectively are typically in the range of 5% to 10% (as compared to the index of refraction of pure GaAs) whereas the index of refraction steps 21c and 23c at heteroboundaries 21 and 23 respectively are about 1% to 2%. The corresponding bandgap steps 20b and 22b at heteroboundaries 20 and 22 respectively are about 300 to 500 meV, whereas the energy steps 21b and 23b at heteroboundaries 21 and 23 respectively are typically about 50 to 100 meV.

Turning now to Fig. 5, there is shown an illustrative embodiment of my invention in which the multi-layered improved DH laser of Fig. 4, part A is mounted upon a heat sink for c.w. operation at room temperature. In the following description materials and dimensions are given for the purposes of illustration only. As discussed previously, the improved DH laser comprises an n-type GaAs substrate 12 about 3—4 mils thick upon which are sequentially fabricated epitaxial layers: an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 14 about 3 μm thick, a first active layer between heteroboundaries 20 and 22 which is about 0.2 μm thick, a second active layer 17 within the first active layer which is typically about 0.1 to 0.03 μm thick, and a p-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 18 which is 1 μm in thickness. Typically region 15 is n-type whereas region 19 is p-type, but the second active layer 17 may be either p-type or n-type.

Before depositing a metallic contact 25 onto the n-type substrate 12, a p-type dopant (e.g., zinc) is typically diffused into p-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ layer 18 to form a shallow (e.g., 0.2 μm) p^+ layer (not shown) to provide good ohmic contact. On p-type layer 18 is deposited an oxide layer 27 having an elongated channel etched therein by well-known photolithographic techniques to define a stripe electrical contact formed by the deposition of a metal layer 29 thereover.

End faces 31 and 33 of the structure are typically cleaved or polished optically flat and perpendicular to the p-n junction (not shown) to form an optical cavity resonator for sustaining coherent radiation generated in the junction. Illustratively, the diode is about 400 μm long and 80 μm wide. One of the end faces is made nearly totally reflective (e.g., face 33) whereas the other (face 31) is made partially transmissive in order to provide a means of egress for the coherent radiation.

In operation the laser diode by means well known in the art is forward-biased and

pumped by a dc source in excess of the lasing threshold. For c.w. operation at room temperature and above, contact 29 may be bonded to a metallized (e.g., tin plated) high thermal conductivity diamond 35 mounted on a tin-plated copper heat sink 37. Due to the difficulty in getting the tin-plating to cover the entire diamond 35, gold wires 39 (about 25 μm in diameter) may be used to ground the tin-plated top surface 41 of the diamond to the heat sink 37. For low thresholds (e.g., 3000 A/cm²) the diamond may be omitted and the diode mounted directly on the copper heat sink. Furthermore, improved heat extraction may be obtained by mounting the diode between a pair of heat sinks.

In the fabrication of our improved DH laser it should be remembered that extremely thin layers are utilized, e.g., the thickness of the first active layer, which serves to provide optical confinement, may be about 0.1 to 0.2 μm whereas the thickness of the second active layer, which serves to confine carriers, may approach an electron diameter (about 100 Å). It is therefore preferable to employ a molecular beam epitaxial growth technique which readily permits the growth of epitaxial layers of III—V compounds as thin as 100 to 200 Å, and is described in our application No. 62287/69 (Serial No. 1270550). That application further describes techniques for growing mixed crystals of III—V compounds such as AlGaAs as well as techniques for introducing into the epitaxial layers either p-type or n-type dopants.

WHAT WE CLAIM IS:—

1. A semiconductor body comprising first and second wide bandgap semiconductor regions of opposite conductivity types, a first narrow bandgap active region between and contiguous with said first and second regions, a second narrow bandgap active region within said first active region, the bandgap of said second active region being smaller than the bandgap of said first active region, a p-n junction located within or coincident with one of the boundaries of said second active region, the arrangement being such that when a suitable operating potential is applied to the body carriers injected under forward bias across said junction are confined to said second active region where they undergo radiative recombination to generate stimulated coherent radiation, said radiation being confined substantially to said first active region, the thickness of said first active region being between approximately $\lambda/2$ and λ , where λ is the wavelength of said radiation as measured in said semiconductor body.

2. A body according to claim 1 wherein said second active region is disposed nearer to the one of said wider bandgap regions which is p-type rather than the wider bandgap region which is n-type.



3. A body according to claim 1 or 2 wherein the difference in bandgap between said wide bandgap regions and said first active region is greater than that between said first and second active regions.

4. A body according to claim 1 or 2 wherein the said first wide bandgap region comprises $\text{Al}_x\text{Ga}_{1-x}\text{As}$, $x > 0$ and said first active region comprises $\text{Al}_y\text{Ga}_{1-y}\text{As}$, $0 \leq y \leq x$.

5. A body according to claim 1, 2 or 3 wherein said first and second wide bandgap regions comprise respectively $\text{Al}_x\text{Ga}_{1-x}\text{As}$ and $\text{Al}_z\text{Ga}_{1-z}\text{As}$, said first active region comprises $\text{Al}_y\text{Ga}_{1-y}\text{As}$, where $y < x$ and $y < z$, and said second active region comprises $\text{Al}_p\text{Ga}_{1-p}\text{As}$ where $0 \leq p < y$.

6. A body according to claim 5 wherein

$$x \approx z, (x-y) \approx (z-y), (x-y) > (y-p)$$

and

$$(z-y) > (y-p).$$

7. A body according to claim 1 comprising the following layers of semiconductor material; a first n-type wide bandgap layer, a second layer thereon having a bandgap smaller than the first layer, a third layer on the second layer having a bandgap smaller than the second layer, a fourth layer on the third layer having a bandgap larger than the fourth layer and a fifth p-type layer having a bandgap larger than the fourth layer.

8. A body according to claim 7 wherein said first layer comprises $\text{Al}_x\text{Ga}_{1-x}\text{As}$, $x > 0$ said second layer comprises

$$\text{Al}_y\text{Ga}_{1-y}\text{As}, 0 < y < x$$

said third layer comprises

$$\text{Al}_p\text{Ga}_{1-p}\text{As}, 0 \leq p < y$$

said fourth layer comprises

$$\text{Al}_q\text{Ga}_{1-q}\text{As}, 0 < q, p < q,$$

and said fifth layer comprises

$$\text{Al}_z\text{Ga}_{1-z}\text{As}, 0 < z, q < z.$$

9. A body according to claim 8 wherein

$$y \approx q < x \approx z, (y-p) < (x-y)$$

and

$$(q-p) < (z-q).$$

10. A laser including a semiconductor body in accordance with any one of claims 1 to 9 and including means forming an optical cavity resonator and means for providing for the emission of radiation from the resonator.

11. A laser according to claim 10 with claim 7, 8 or 9 including a heat sink thermally coupled to the fifth layer so that it is capable of c.w. operation at room temperature.

12. A laser according to claim 11 including a stripe electrical contact to the fifth layer.

13. A semiconductor body substantially as herein described with reference to Fig. 4 of the drawings.

14. A laser substantially as herein described including a semiconductor body according to claim 13.

15. A laser substantially as herein described with reference to and as shown in Fig. 5 of the drawings.

P. S. BROWN,
Chartered Patent Agent,
5, Mornington Road,
Woodford Green, Essex.
Agent for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1974.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

